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ARTIFICIALLY INDUCED TRANSITION RESULTS FROM A 7-DEG, 14-7-DEG BICONIC, AND 5-DEG CONE AT MACH 9 IN THE AEDC-VKF TUNNEL F

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ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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Tests are described which measured the artificially induced transition location on a slightly blunted 7-deg cone. Various distributed roughness and spherical type boundary layer trips were used. The tests were conducted at Mach 9 over a free stream Reynolds number range from 0.5×10^6/ft to 20×10^6/ft. Test results are not included in the report.

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NOMENCLATURE

ALPHA	Model angle of attack, deg
HO	Total enthalpy of gas, Btu/lbm
ℓ	Axial model length (Sharp)
ℓ_b	Axial model length with blunt nose, measured from stagnation point, in.
ℓ_n	Axial length of nose only, measured from stagnation point, in. (see Fig. 4)
M-INF	Free-stream Mach number
P	Model pressure, psia
P-INF	Free-stream static pressure, psia
PO	Reservoir pressure, psia
POP, PREF	Total pressure behind the normal shock, psia
Q-INF	Free-stream dynamic pressure, psia
Q	Heat-transfer rate, Btu/ft^2-sec
QO, QREF	Stagnation heat-transfer rate on a hemisphere cylinder referenced to 0.589-in. radius
R	Gas constant
RB	Model base radius, in.
RE/FT	Free-stream unit Reynolds number, per ft
RN	Model nose radius, in.
S	Surface distance measured from stagnation, in.
ST	Stanton number based on QO
s_∞	Free-stream entropy
T-INF	Free-stream static temperature, °R
TO	Reservoir temperature, °R
T_w	Model wall temperature, °R
TIME	Test section time, msec
V-INF	Free-stream velocity, ft/sec
ϕ	Model circumferential angle, deg

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force System Command (AFSC), at the request of the Space and Missile Systems Organization (SAMSO/RSSE) under Program Element 63311F. Mr. Elton Thompson of AEDC/DOTR was the project monitor. The results of the test were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number V41F-56.

The test were conducted in the Hypervelocity Wind Tunnel (F), von Karman Gas Dynamics Facility (VKF), AEDC from July 13, 1978 through Aug. 16, 1978. The test objective was to measure transition position on various configurations using several types of boundary layer trips. The tests were conducted at a nominal free-stream Mach number of 9 and over a free-stream Reynolds number range from 0.5×10^6/ft to 20×10^6/ft. Inquiries for copies of the test data should be directed to AEDC/DOTR, Arnold AFS, Tennessee, 37389. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 WIND TUNNEL

The Hypervelocity Wind Tunnel F (Fig. 1) is an arc-driven wind tunnel of the hotshot type (Refs. 1 and 2) and capable of providing Mach numbers from about 7 to 13 over a Reynolds number per ft range from 0.2×10^6 to 50×10^6. Tests are conducted in a family of three contoured nozzles. The three axisymmetric, contoured nozzles have 25-in., 40-in., and 48-in. exit diameters, which connect to the 54-in.-diam test station and provide a free-jet exhaust (Fig. 2). The test gas for aerodynamic and aerothermodynamic testing is nitrogen. Air is used for combustion tests. The test gas is confined in either a 1.0-cu-ft, 2.5-cu-ft, or a 4.0-cu-ft arc-chamber where it is heated and compressed by an electric arc discharge. The increase in pressure results in a diaphragm rupture with the subsequent flow expansion through the nozzle. Test times are typically from 50 to 200 msec. Shadowgraph, schlieren, and holography coverage is available at the 54-in. diam test station.

This test was conducted using the 40-in.-exit-diam contoured nozzle in the 54-in.-diam test section to obtain a nominal free-stream Mach number of 9. A tunnel installation sketch is presented in Fig. 3. Nitrogen was the test gas. The 4-cu-ft arc chamber was used, and useful test times up to approximately 100 msec were obtained. Because of the relatively short test times, the model wall temperature remained essentially invariant from the initial value of approximately 540°R, thus $T_w/TO \simeq 0.20$ to 0.38 which approximates the condition of practical interest for re-entry vehicles.

2.2 MODEL

The test articles (existing VKF models) consisted of a 43.753 inch (blunt length) cone illustrated in Fig. 4 to which a 14-deg biconic nose could be added (Fig. 5) and a 5-deg cone illustrated in Fig. 6. Details of gage locations are presented in Tables 1, 2, and 3 of Appendix B. The

nominal surface roughness for all models was 32 microinches. Both distributed roughness and spherical type boundary layer trips were used. Their application to the various models is shown in Table 4 and trip details are given in Table 5 of Appendix B.

A small boundary layer survey rake was attached to the base of the 7-deg model on all runs as shown in Fig. 7. The rake was not used on the 5-deg model.

2.3 INSTRUMENTATION AND MEASUREMENT ACCURACY

2.3.1 Test Conditions

The test section was instrumented with various probes to monitor the tunnel conditions. These probes comprised two hemisphere cylinders instrumented with coaxial heat-transfer gages and two pitot pressures. The probes were mounted at an appropriate distance from the model to eliminate shock interference. In addition, four static pressure transducers were installed at Sta 365 in the 40-inch diam nozzle.

The diameter of the hemisphere cylinder heat probes was selected as the maximum size that would maintain a laminar boundary layer at the shoulder gage locations. This criterion dictated 1/2-in-diam probes at the Mach 9 test condition. The hemisphere cylinders were instrumented with coaxial surface thermocouples to measure the heat transfer rate at the stagnation and shoulder location. The reference stagnation heat transfer rate QREF on a sphere was obtained by inferring the shoulder readings to the stagnation point.

Pressure measurements were obtained using standard AEDC-VKF strain-gage transducers. The free-stream pitot pressure POP was measured with 15-, 100-, or 300-psid transducers featuring a sealed reference port. The nozzle static pressure measurements were obtained with 1- or 15-psid transducers referenced to vacuum or atmosphere, respectively. These pitot and static measurements are used to determine free stream Mach number (see Section 3.2).

Transducer accuracy is defined as a bandwidth which includes 95 percent of the calibration residuals, i.e. 2σ deviations. Based on periodic comparisons with secondary standards, the accuracy of the pressure transducers is estimated to be ±1 percent of their reading. Likewise, coaxial thermocouple accuracy is estimated to be ±3 percent of their reading based upon laboratory calibrations and comparison with a working standard.

2.3.2 Model Instrumentation

Model pressures were measured with internally mounted pressure transducers built and installed by AEDC-VKF. For pressures greater than 1 psid, a wafer style semiconductor strain gage transducer with a sealed reference port was used. For pressures less than 1 psid, a similar wafer transducer was used with the reference port at near vacuum pressure. The wafer transducer is nominally 0.56 in. diam by 0.25 in. thick. Application of a differential pressure produces a force on the metal

diaphragm. The diaphragm is instrumented with two semiconductor strain gages which sense the deflection. Based on periodic comparisons with secondary standards, the accuracy of these transducers is estimated to be ±1 percent of reading.

Coaxial surface thermocouple gages built and installed by AEDC-VKF were used to measure the surface heating rate distributions. The coaxial gage consists of an electrically insulated Chromel® center conductor enclosed in a cylindrical constantan jacket. After assembly and installation in the model, the gage materials are blended together with a jeweler's file. This results in thermal and electrical contact between the two materials in a thin layer at the surface of the gage; i.e., a surface thermocouple. A second result of filing the gage surface is the opportunity for "perfect" contouring of the gage to the model surface, a fact that is important for transition studies since no measurable steps or gaps are introduced by the gages.

In practical measurement applications, the surface thermocouple behaves as a homogeneous, one-dimensional, semi-infinite solid. The instrument provides an electromotive force (E.M.F.) directly proportional to surface temperature which may be related by theory to the incident heat flux. All heat-transfer gages were bench calibrated prior to their installation into the model. Based on periodic comparisons with the working standard, the accuracy of the gage is estimated to be ±3 percent of reading.

All instrumentation discussed was developed at AEDC specifically for Tunnel F applications. Further description and discussion can be found in Refs. 2, 3, and 4.

3.0 PROCEDURES

3.1 TEST PROCEDURES

The primary test variables were model cone angle, trip configuration, and Reynolds number. Angle-of-attack was held at zero. The minature boundary layer survey rake was installed at the aft end of the 7-deg cone and biconic model, but not used on the 5-deg cone. The objective of each run was to establish the "effective point" of each trip configuration; i.e. the Reynolds number at which the trip produces fully turbulent flow over the entire model. A complete listing of pertinent variables is presented in the Run Summary (Table 4, Appendix B).

3.2 TEST CONDITIONS

The method of determining the tunnel flow conditions is briefly summarized as follows: instantaneous values of nozzle static pressure and pitot pressure POP are measured, and an instantaneous value of the stagnation heat transfer rate QREF is inferred from a direct measurement of shoulder heat rates on the hemisphere cylinder heat probes. Total enthalpy(HO) is calculated from POP and QREF and the heat probe radius, using fay-Riddell theory, Ref. 5. The free-stream static pressure is

obtained from the nozzle static pressures in a correlation determined from previous detail tunnel calibrations. The Mach number is calculated from the isentropic relationship using the test section pitot pressure and static pressure.

The centerline pitot pressure on the test model, the Mach number and HO are then used to calculate the free-stream conditions from isentropic flow equations and the normal shock relationships. The isentropic reservoir conditions are read from tabulated thermodynamic data for nitrogen (Ref. 6) using HO and s_∞/R. The equations for this procedure are contained in Refs. 7 and 8.

Test conditions for this test were

Condition	~M-INF	~TO °R	~(RE/FT x 10^{-6})Range
1	9	1800	18 to 8
2	↓	2000	12 to 5
3		2200	5 to 3
4		2500	3 to 0.5

3.3 DATA ACQUISITION AND REDUCTION

The model data (pressure and heat transfer rate) and the tunnel monitor probe data were recorded on the Tunnel F Transient Data System (TDS). The TDS is capable of scanning the 100 available data channels at preselected rates (normally 100,000 samples/sec). Data for an entire run were stored on the disk unit of a PDP 11/40 Computer which is an integral part of the TDS. The run data plus calibration results and model constants are transmitted to an off line digital computer for final data reduction.

Since Tunnel F operates with a constant volume reservoir with an initial charge density, the reservoir conditions decay with time. As a result, all tunnel conditions and model data results vary with time during the useful data range. Nondimensional values such as M-INF and model pressure/POP are relatively constant with time. Timewise variations in Reynolds number permit acquisition of data at different Reynolds numbers for the same run.

4.0 DATA UNCERTAINTY

4.1 TEST CONDITIONS

The accuracy of the transducer output (pressure and heat transfer rate) under laboratory conditions was discussed in Section 2.3. The uncertainties of measured data, however, are higher due to the dynamics of the measurements and system errors. The uncertainties in the monitor probe measurements (POP and QO) were estimated considering both the static load calibrations and the repeatability of the test section pitot profiles. The uncertainty in the pressure data (POP) is estimated to be ±4 percent for a single measurement and ±3 percent based on an average of two measurements. The heat transfer rate (QO) uncertainty is ±9 percent based on a single measurement and ±5 percent based on an average of four measurements. The uncertainty in the Mach number (M-INF) determined from the nozzle static pressure correlation is ±3 percent.

The accuracy (based on 2σ deviation) of the basic tunnel parameters, POP, QO and M-INF (see Section 2.3) was combined by the Taylor series method of error propagation to estimate uncertainties in the other free-stream parameters using Eq. (1).

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1}\,\Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2}\,\Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3}\,\Delta X_3\right)^2 \cdots + \left(\frac{\partial F}{\partial X_n}\,\Delta X_n\right)^2 \qquad (1)$$

where ΔF is the absolute uncertainty in the dependent parameter $F = f(X_1, X_2, X_3, \ldots X_n)$ and X_n are the independent parameters (or basic measurements). ΔX_n are the uncertainties (errors) in the independent measurements (or variables). Representative uncertainties are given below:

UNCERTAINTY ±, PERCENT

P-INF	T-INF	RE/FT
7	8	11

4.2 MODEL DATA

The uncertainty estimates for the model heat-transfer rate and pressure data are given below in terms of the absolute level measured. The reference heat transfer rate, QO, uncertainty is ±5 percent and POP is ±3 percent. Therefore, the uncertainty of the nondimensional ratio Q/QO and P/POP by the Taylor series method of error propagation (Eq. 1) yields the following:

UNCERTAINTY (±), PERCENT

Q Range Btu/ft^2-sec	Q	Q/QO
> 1.0	9	10
0.2 → 1.0	14	15

P Range psia	P	P/POP
>0.5	4	5
<0.5	9	10

5.0 DATA PACKAGE PRESENTATION

A sample of the test results in the form of tabulated timewise data and computer generated plots is presented in Appendix C. The timewise variation of Reynolds number during a typical Tunnel F run makes it particulary attractive for transition type testing. Sufficient time-points were provided on all runs such that variations in transition location can be observed.

Experimental results are shown in Fig. 8 for the case of run 6010. Comparison of these results with laminar and turbulent theory shows excellent agreement which is considered adequate validation of the data quality.

These data represent an expansion of earlier work by Boudreau (Ref. 9) and may be compared directly with those results.

6.0 REFERENCES

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9. Boudreau, A. H. "Artifically Induced Boundary Layer Transition on Blunt-Slender-Cones Using Distributed Roughness and Spherical Type Tripping Devices at Hypersonic Speeds" AEDC-TR-77-120, February 1978 or AIAA Paper 78-1127 presented at the 11th Fluid and Plasma Dynamics Conference, Seattle, Washington, July 10-12, 1978.

APPENDIX A

ILLUSTRATIONS

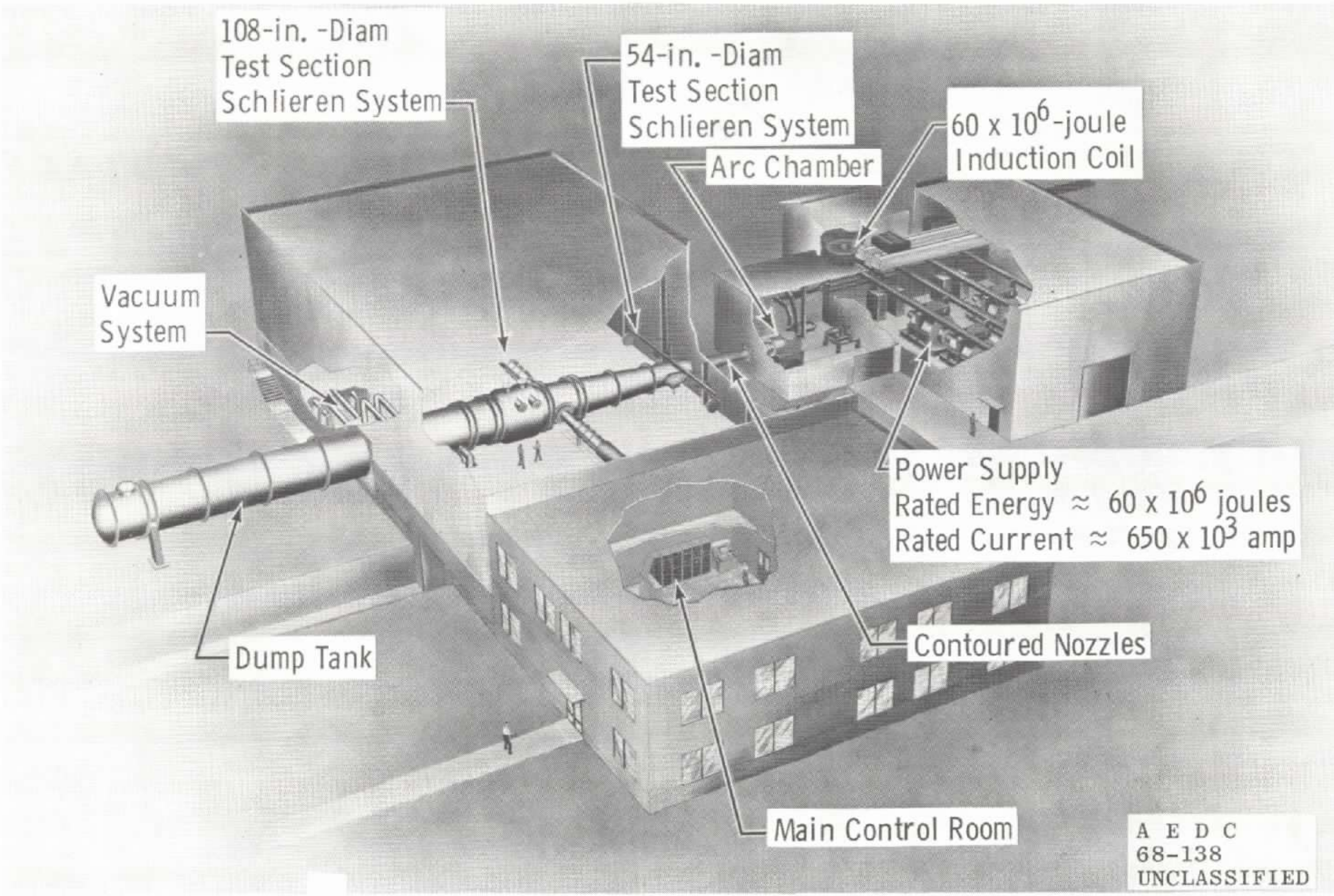


Figure 1. AEDC-VKF Tunnel F Plant.

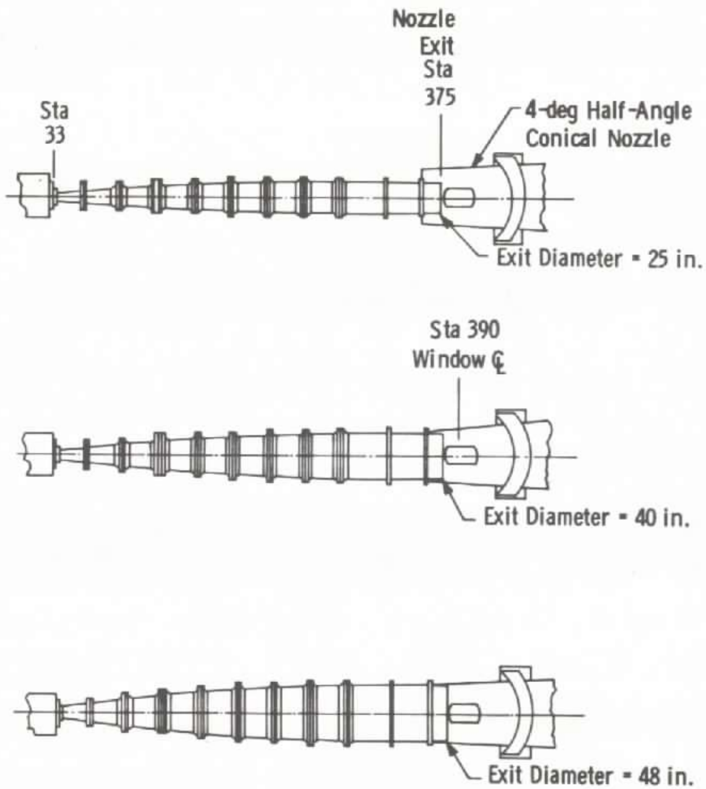
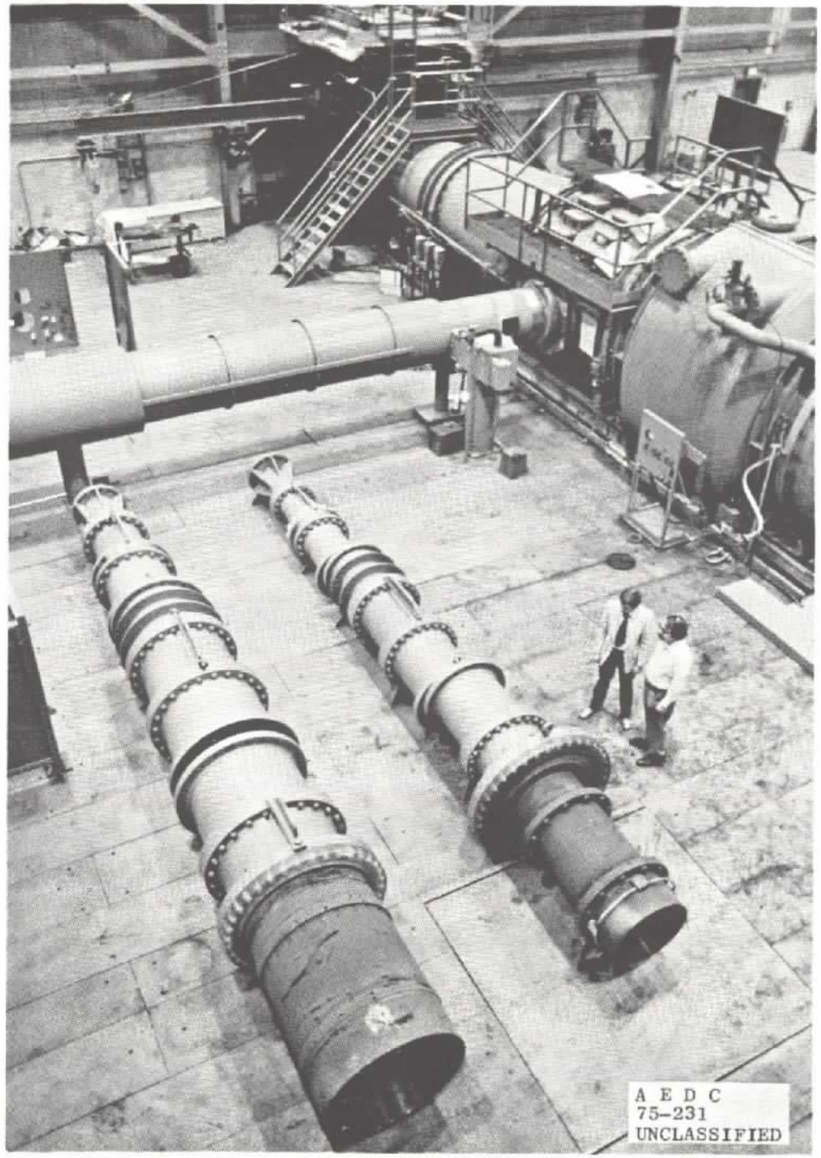


Figure 2. Tunnel F family of contoured nozzles.



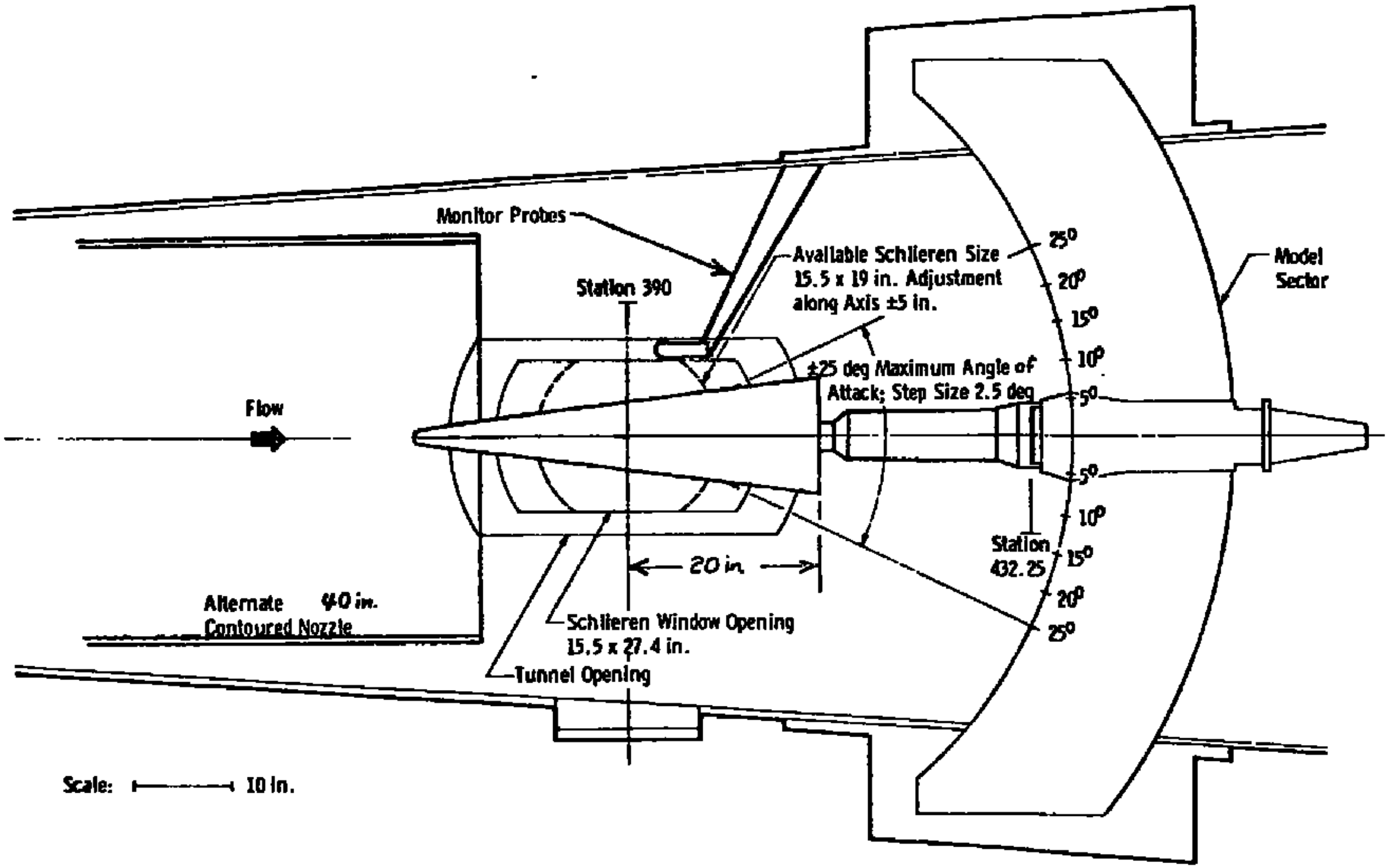


Fig. 3 Model Installation

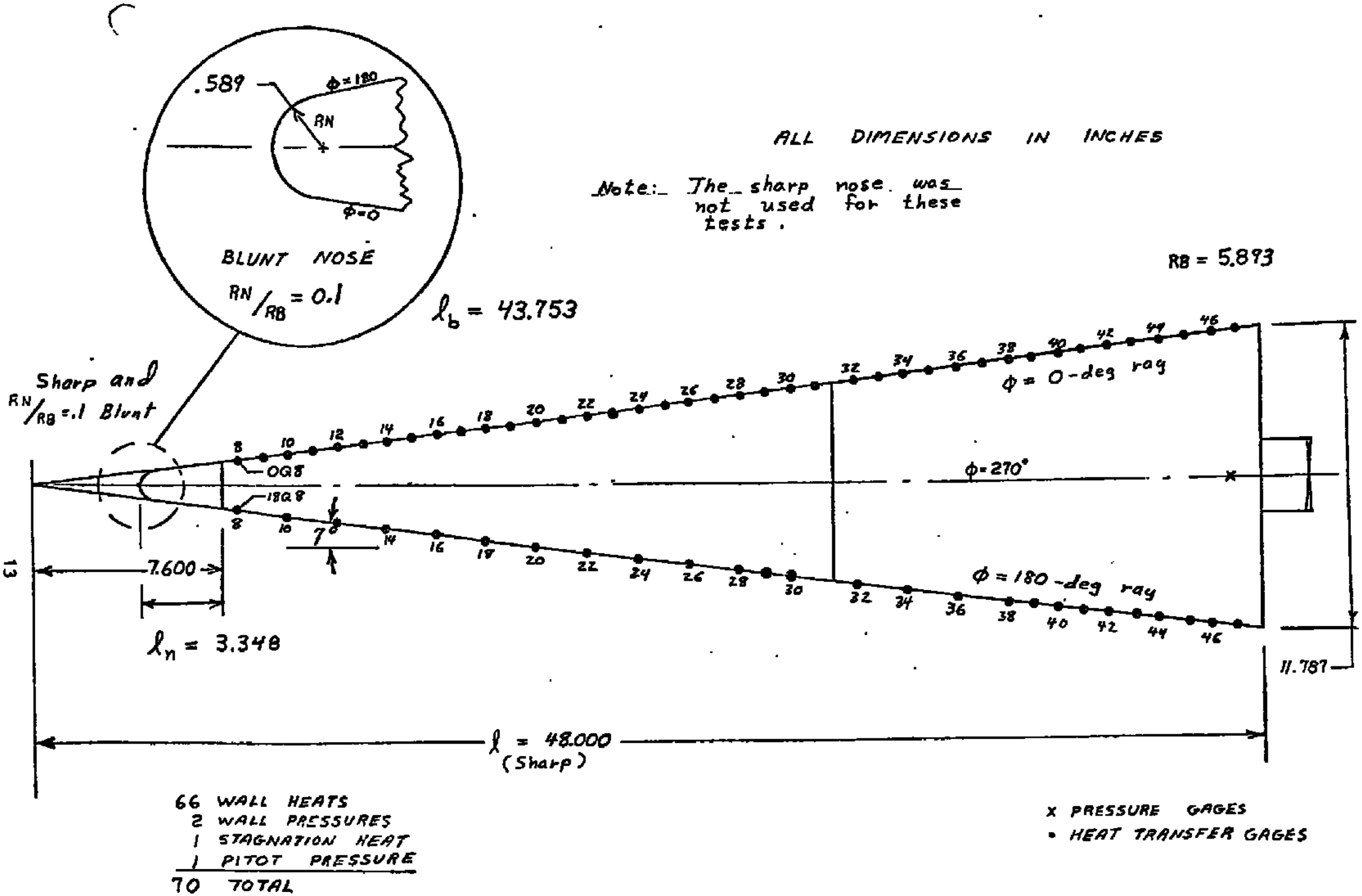


Fig. 4 Model Details - Seven Degree Cone

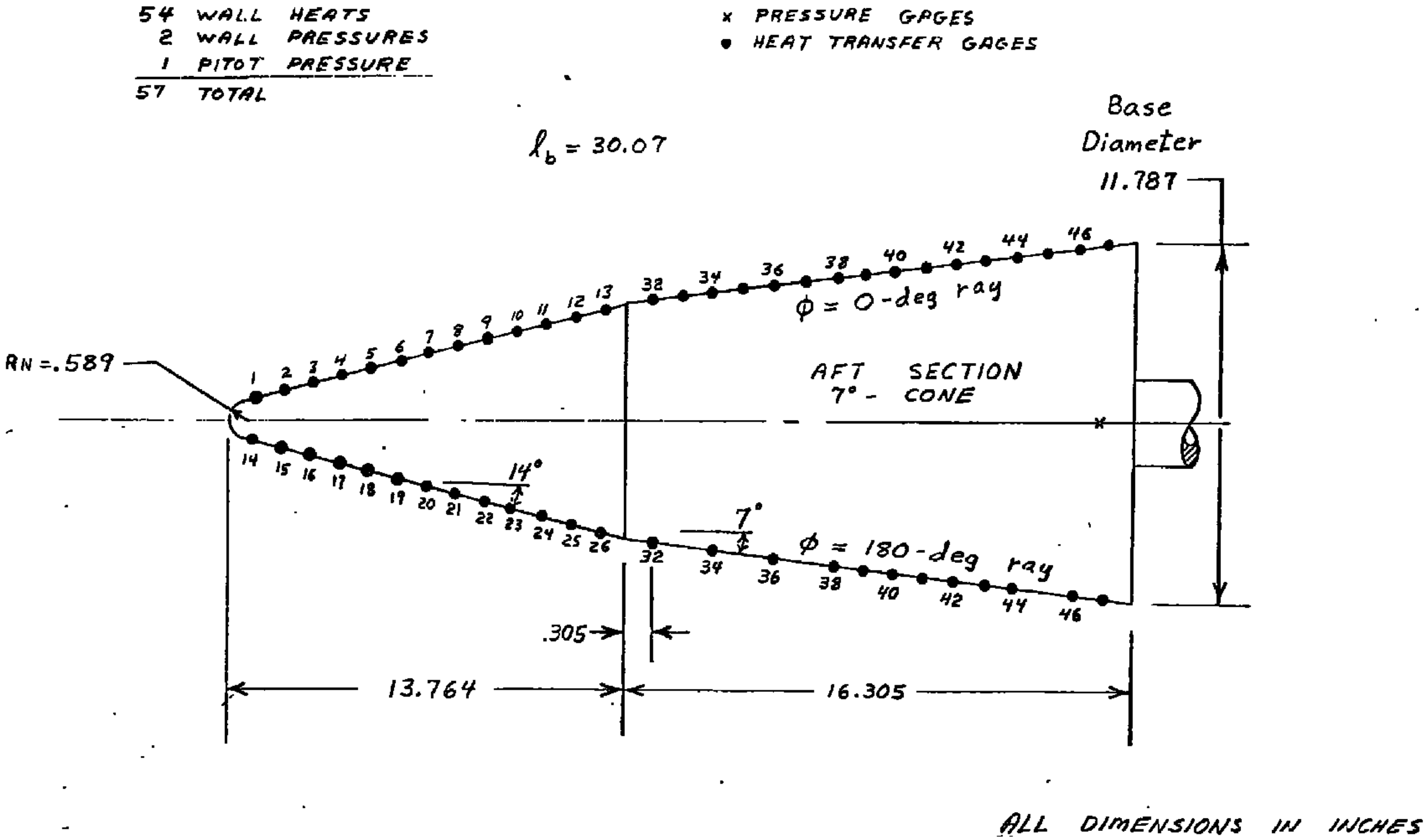


Fig. 5 The 14-7-deg. Bi-conic Model

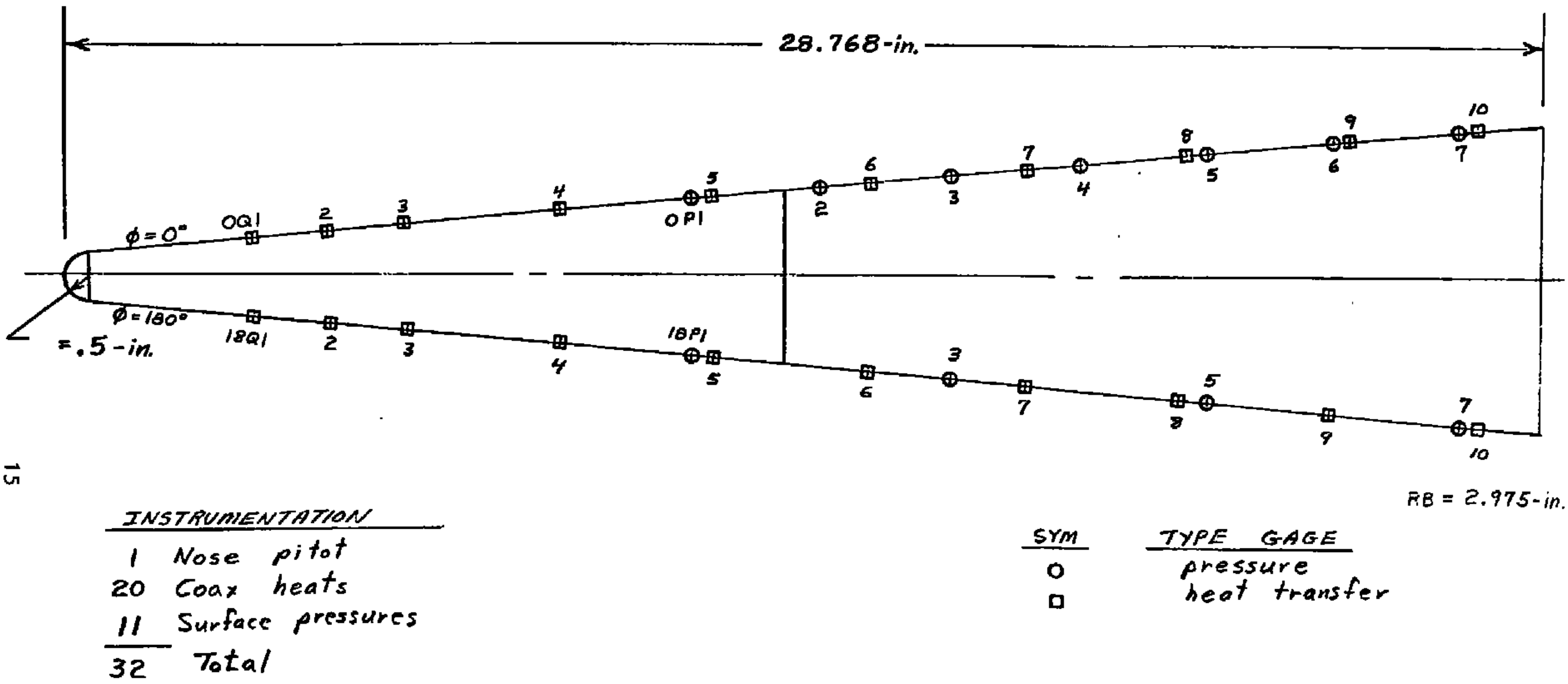
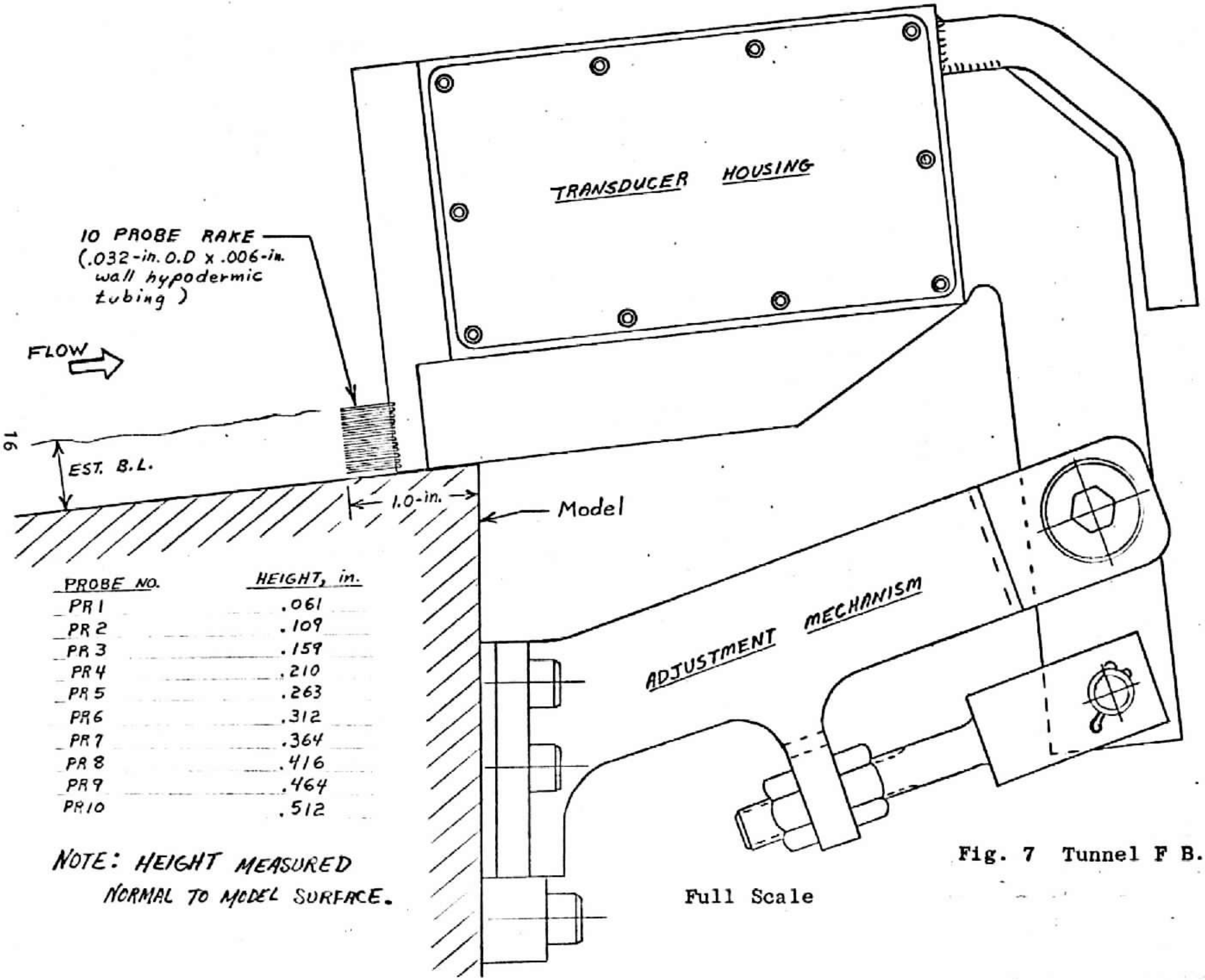


Fig. 6 The 5-Deg. Cone Model



PROBE NO.	HEIGHT, in.
PR 1	.061
PR 2	.109
PR 3	.159
PR 4	.210
PR 5	.263
PR 6	.312
PR 7	.364
PR 8	.416
PR 9	.464
PR 10	.512

NOTE: HEIGHT MEASURED NORMAL TO MODEL SURFACE.

Full Scale

Fig. 7 Tunnel F B. L. Rake

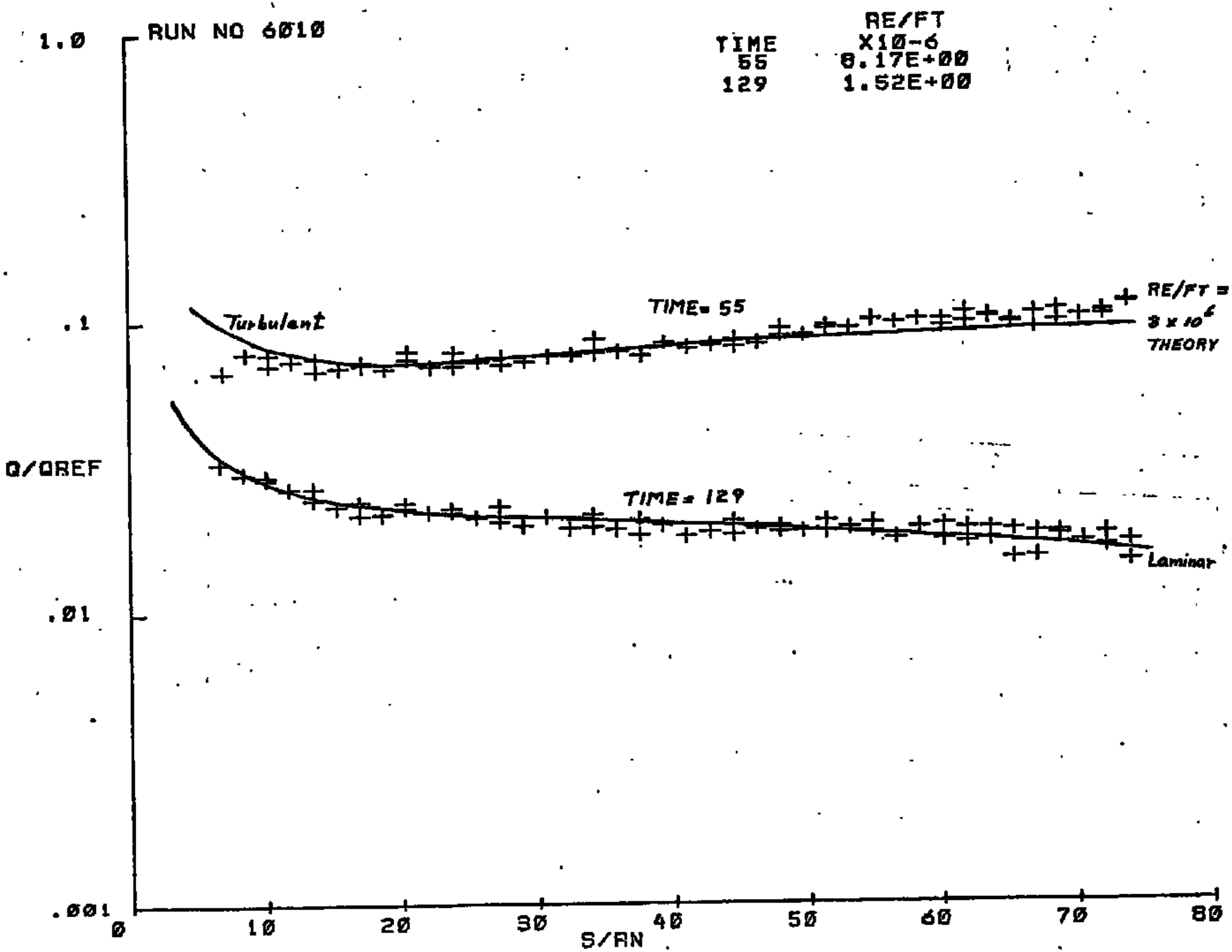


Fig. 8 Comparison of Experimental Data and Theory

APPENDIX B

TABLES

TABLE 1

S, S/R_N for 7-deg Cone

Gage Name	S inches	S/R_N	Gage Name	S inches	S/R_N
OQ6	1.95	3.31	OQ27	23.25	39.47
OQ7	2.95	5.01	OQ28	24.26	41.19
OQ8	4.06	6.89	OQ29	25.27	42.90
OQ9	5.08	8.62	OQ30	26.28	44.62
OQ10	6.09	10.33	OQ31	27.29	46.33
OQ11	7.10	12.05	OQ32	28.30	48.05
OQ12	8.11	13.77	OQ33	29.31	49.76
OQ13	9.13	15.50	OQ34	30.32	51.48
OQ14	10.14	17.22	OQ35	31.32	53.17
OQ15	11.15	18.93	OQ37	33.34	56.60
OQ16	12.16	20.65	OQ39	35.36	60.03
OQ17	13.17	22.36	OQ41	37.39	63.48
OQ18	14.18	24.07	OQ43	39.39	66.89
OQ19	15.19	25.79	OQ45	41.41	70.31
OQ20	16.20	27.50	OQ47	43.44	73.75
OQ21	17.21	29.22	90P47	43.44	73.75
OQ22	18.22	30.93	27P47	43.44	73.75
OQ23	19.22	32.63			
OQ24	20.23	34.35			
OQ25	21.24	36.06			
OQ26	22.24	37.76			

TABLE 2

S, S/R_N for Biconic Model

Gage Name	S inches	S/R_N
14Q1	1.42	2.41
14Q2	2.45	4.16
14Q3	3.48	5.91
14Q4	4.51	7.66
14Q5	5.54	9.41
14Q6	6.57	11.15
14Q7	7.60	12.90
14Q8	8.63	14.65
14Q9	9.66	16.40
14Q10	10.69	18.15
14Q11	11.72	19.90
14Q12	12.75	21.65
14Q13	13.78	23.40
14Q14	1.42	2.41
14Q15	2.45	4.16
14Q16	3.48	5.91
14Q17	4.51	7.66
14Q18	5.54	9.41
14Q19	6.57	11.15
14Q20	7.60	12.90
14Q21	8.63	14.65
14Q22	9.66	16.40
14Q23	10.69	18.15
14Q24	11.72	19.90
14Q25	12.75	21.65
14Q26	13.78	23.40

Gage Name	S inches	S/R_N
OQ32	14.81	25.14
OQ33	15.82	26.86
OQ34	16.83	28.57
OQ35	17.84	30.29
OQ36	18.84	31.99
OQ37	19.85	33.70
OQ38	20.85	35.40
OQ39	21.86	37.11
OQ40	22.87	38.83
OQ41	23.88	40.54
OQ42	24.89	42.26
OQ43	25.90	43.97
OQ44	26.90	45.67
OQ45	27.91	47.39
OQ46	28.92	49.10
OQ47	29.92	50.80
18Q32	14.81	25.14
18Q34	16.83	28.57
18Q36	18.84	31.99
18Q38	20.85	35.40
18Q39	21.86	37.11
18Q40	22.87	38.83
18Q41	23.88	40.54
18Q42	24.89	42.26
18Q43	25.90	43.97
18Q44	26.90	45.67
18Q46	28.92	49.10
18Q47	29.92	50.80
90P47	29.92	50.80
27P47	29.92	50.80

TABLE 3

S, S/R_N for 5-deg Cone

Gage Name	S inches	S/R_N	Gage Name	S inches	S/R_N
OQ1	5.00	10.00	OP1	12.50	25.00
OQ2	6.25	12.50	OP2	15.00	30.00
OQ3	7.50	15.00	OP3	17.50	35.00
OQ4	10.00	20.00	OP4	20.00	40.00
OQ5	12.90	25.80	OP5	22.50	45.00
OQ6	15.90	31.80	OP6	25.00	50.00
OQ7	18.90	37.80	OP7	27.50	55.00
OQ8	21.90	43.80			
OQ9	24.50	49.00			
OQ10	27.90	55.80			
18Q1	5.00	10.00	18P1	12.50	25.00
18Q2	6.25	12.50	18P3	17.50	25.00
18Q3	7.50	15.00	18P5	22.50	45.00
18Q4	10.00	20.00	18P7	27.50	55.00
18Q5	12.90	25.80			
18Q6	15.90	31.80			
18Q7	18.90	37.80			
18Q8	21.90	43.80			
18Q9	24.90	49.80			
18Q10	27.90	55.80			

Table 4
Run Summary

SAMSO / DOTR Hypersonic Turb. B.L. Invest. Phase 7

July - August 1978

M-INF ≈ 9

Model	Trip Configuration[1]	RE/FT^{-6} range	Run Number
7-deg Cone	Smooth - No trip	6.3 → 20.3	6005
	5-mil Grit Blast	6.0 → 20.5	6006
	" " "	1.1 → 10.4	6010
	8-mil NCM	2.5 → 10.0	6013
	14-mil Grit	1.8 → 5.1	6007
	14-mil NCM	1.7 → 4.5	6008
	40-mil Grit	.5 → 3.1	6009
	.063 & .109-in Spherical	1.9 → 5.9	6011
↓	" " "	2.0 → 8.1	6012
			*
14-deg, 7-deg Biconic	Smooth - No trip	7.6 → 20.8	6016
	10-mil Grit	2.2 → 10.3	6019
	14-mil Grit	2.0 → 5.2	6017
↓	.039-in. Spherical	1.7 → 5.1	6018
5-deg Cone	10-mil Grit	5.1 → 18.2	6023
	" "	2.3 → 10.3	6024
	14-mil Grit	2.0 → 10.1	6020
	20-mil Grit	1.5 → 10.0	6021
↓	36-mil Grit	1.7 → 10.5	6022

* Note: Runs 6014 and 6015 were not part of this test.

[1] See Table 5 for details of trip configurations

Table 5
Trip Description

Type of Trip	Description
Grit Blast	Surface roughness was produced by impacting hardened steel particles onto the stainless steel nose. RMS peak-to-valley roughness height was 5-mils. Roughness extended from $S/R_N = 0$ to 5.
Numerically Controlled Machine (NCM)	Roughness elements were machined as pyramids with a total height (peak-to-valley) of 8 and 14-mils. The base plane of the pyramids was recessed 1/3 of the height below the original unaltered model surface. The roughness extended from $S/R_N = .10$ to 5.
Grit	Roughness elements consisted of silicon carbide grit particles bonded to the model surface with expoxy. Grit sizes of 10, 14, 20, 36, and 40 mils were used and coverage extended from $S/R_N = .8$ to 5.
.063 & .109-in. Spheres (7-deg. Model)	Tripping elements consisted of two rows of spheres: a row of .063-in spheres at $S/R_N = 3.1$ and a row of .109-in spheres at $S/R_N = 6.5$. Lateral spacing was four diameters. The spheres were spot welded to thin metal bands which were then bonded to the model.
.039-in. Spheres (14-7-deg Biconic)	Tripping elements consisted of a single row of .039-in. spheres at $S/R_N = 6.8$. The spheres were laterally spaced four diameters apart and spot welded to thin metal bands which were then bonded to the model surface.

APPENDIX C

SAMPLE TABULATED DATA

SVERDRUP-ARO, INC. AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
HYPERVELOCITY WIND TUNNEL F
ARNOLD AIR FORCE STATION, TN.

SAMSO/DOTR TURB. B.L. TEST V41F-56 DATE 23-AUG-78 PROJECT ENGINEER A.H.BOUDREAU
RUN 6016
ALPHA 0.

Q0,ST ,BASED ON .589 INCH RADIUS
MODEL LENGTH = 48.00 INCHES

TIME MSEC	P-INF PSIA	T-INF DEG R	V-INF FT/SEC	M-INF	Q-INF PSIA	RE/FT X10-6	PO PSIA	TO DEG R	HO BTU/LBM	Q0 BTU/FT2-SEC	ST	POP PSIA	PREF PSIA
66	0.4585	101.0	4441.	8.86	25.21	20.78	7414.	1584.	4.19E+02	84.66	9.12E+02	46.71	46.71
69	0.4391	105.0	4545.	8.87	24.16	18.57	7219.	1656.	4.39E+02	89.08	9.53E+02	44.77	44.77
83	0.3740	115.2	4867.	9.09	21.64	14.27	7485.	1872.	5.02E+02	102.82	1.08E+03	40.15	40.15
100	0.3319	130.5	5024.	8.82	18.07	10.19	5758.	2009.	5.36E+02	103.53	1.15E+03	33.55	33.55
117	0.2939	138.4	5056.	8.62	15.28	8.07	4521.	2050.	5.45E+02	97.31	1.16E+03	28.38	28.38
132.	0.2574	132.2	4936.	8.61	13.35	7.56	3936.	1967.	5.19E+02	85.00	1.11E+03	24.78	24.78

SVERDRUP-ARO, IC. AEDC DIVISION
VON KARMAN GA. DYNAMICS FACILITY
HYPERVELOCITY WIND TUNNEL F
ARNOLD AIR FORCE STATION, TN.

SAMSO/DOTR TURB. B.L. TEST V41F-56 DATE 23-AUG-78 PROJECT ENGINEER A.H.BOUDREAU
RUN 6016
ALPHA 0.

PRESSURE DATA

PRESSURE, PSI

TIME	27P47	PR1	PR2	PR3	PR4	PR5	PR7	PR8	PR9	PR10
66	1.0809E+00	1.3801E+01	2.2452E+01	3.0883E+01	4.7393E+01	6.8292E+01	8.7309E+01	8.6350E+01	8.4596E+01	7.2122E+01
69	1.0495E+00	1.4125E+01	2.3306E+01	3.1307E+01	4.8298E+01	6.6645E+01	8.2593E+01	8.1719E+01	8.0083E+01	6.8309E+01
83	9.9899E-01	1.3430E+01	2.1831E+01	2.8454E+01	4.3292E+01	5.9165E+01	7.0502E+01	7.0181E+01	6.8593E+01	5.8807E+01
100	8.7360E-01	1.1359E+01	1.8541E+01	2.3714E+01	3.5954E+01	4.8307E+01	5.7681E+01	5.7563E+01	5.6408E+01	4.8823E+01
117	7.4730E-01	9.8419E+00	1.6203E+01	2.0557E+01	3.0647E+01	4.0785E+01	4.8582E+01	4.8724E+01	4.7914E+01	4.2080E+01
132	6.4892E-01	8.7094E+00	1.4553E+01	1.8495E+01	2.7349E+01	3.5807E+01	4.2726E+01	4.2813E+01	4.1982E+01	3.7333E+01

TIME	90P47
66	1.1087E+00
69	1.0717E+00
83	1.0224E+00
100	8.8487E-01
117	7.6050E-01
132	6.6327E-01

P / PREF

TIME	27P47	PR1	PR2	PR3	PR4	PR5	PR7	PR8	PR9	PR10
66	2.3141E-02	2.9547E-01	4.8091E-01	6.6121E-01	1.0147E+00	1.4621E+00	1.8693E+00	1.8488E+00	1.8112E+00	1.5441E+00
69	2.3442E-02	3.1550E-01	5.2056E-01	6.9926E-01	1.0789E+00	1.4886E+00	1.8445E+00	1.8252E+00	1.7887E+00	1.5255E+00
83	2.4884E-02	3.3452E-01	5.4379E-01	7.0877E-01	1.0784E+00	1.4737E+00	1.7561E+00	1.7481E+00	1.7086E+00	1.4548E+00
100	2.6039E-02	3.3853E-01	5.5260E-01	7.0677E-01	1.0716E+00	1.4421E+00	1.7191E+00	1.7156E+00	1.6835E+00	1.4551E+00
117	2.6336E-02	3.4684E-01	5.7102E-01	7.2446E-01	1.0800E+00	1.4373E+00	1.7121E+00	1.7171E+00	1.6886E+00	1.4830E+00
132	2.6185E-02	3.5145E-01	5.8724E-01	7.4632E-01	1.1036E+00	1.4449E+00	1.7241E+00	1.7276E+00	1.6941E+00	1.5065E+00

TIME	90P47
65	2.3737E-02
69	2.3937E-02
83	2.5467E-02
100	2.6372E-02
117	2.6801E-02
132	2.6765E-02

SVERDRUP-ARO, C. AEDC DIVISION
VON KARMAN GA. DYNAMICS FACILITY
HYPERVELOCITY WIND TUNNEL F
ARNOLD AIR FORCE STATION, TN.

SAMSO/DOTR TURB. B.L. TEST V41F-56 DATE 23-AUG-78 PROJECT ENGINEER A.H.BOUDREAU
RUN 6016
ALPHA 0.

HEAT-TRANFER DATA

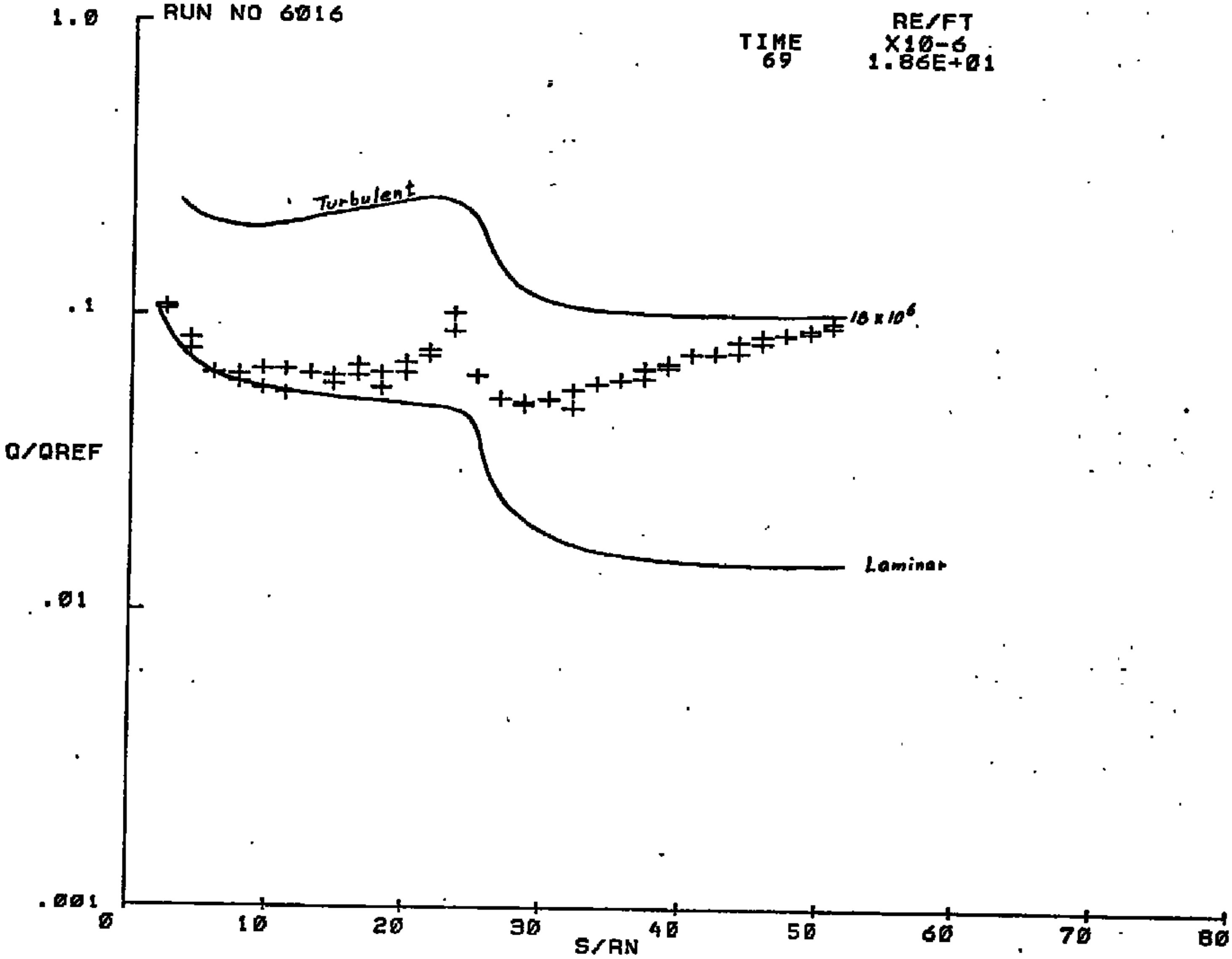
HEAT TRANSFER RATE, BTU/FT2-SEC

TIME	14Q1	14Q2	14Q3	14Q4	14Q5	14Q6	14Q7	14Q8	14Q9	14Q10
66	8.9699	7.1682	5.4367	5.3774	4.8336	4.6878	5.5219	5.5822	5.8450	5.7771
69	9.3591	7.4741	5.6791	5.6298	5.0321	4.8386	5.6671	5.5699	5.5967	5.7216
83	10.3689	8.2856	6.4526	6.4217	5.7852	5.4231	6.2863	6.1515	6.0897	6.1927
100	9.9902	7.9279	6.3787	6.3483	5.8153	5.3514	6.0599	6.0279	5.9242	5.5035
117	9.0155	7.1649	5.8433	5.8121	5.3371	4.7618	5.4424	5.3576	5.2888	5.2953
132	7.4158	5.9166	4.8285	4.8762	4.3694	3.9447	4.4273	4.3476	4.2852	4.1030

TIME	14Q11	14Q12	14Q13	14Q14	14Q15	14Q17	14Q18	14Q19	14Q20	14Q21
66	6.1332	7.3200	8.8120	9.1029	6.5298	4.9949	5.6372	5.6372	5.5579	5.0989
69	5.7037	6.5421	7.9514	9.5394	6.7773	5.2902	5.8776	5.8526	5.6869	5.2265
83	6.1309	6.8773	8.2312	10.6710	7.2677	5.9827	6.5911	6.5169	6.4198	5.8323
100	5.8205	6.4218	7.2511	10.3400	6.8740	5.7028	6.3585	6.2154	5.9103	5.4214
117	5.0809	5.6850	6.5034	9.3970	6.0874	5.0683	5.5690	5.4839	5.1389	4.5402
132	3.9788	4.3532	5.0852	7.5787	4.8755	4.0599	4.5804	4.4885	4.2089	3.7660

TIME	14Q22	14Q23	14Q24	14Q25	14Q26	0Q32	0Q33	0Q34	0Q35	0Q36
66	6.0857	5.1340	6.6249	7.1844	9.9322	6.1056	5.0916	4.6010	4.6942	4.9401
69	6.0676	5.0530	6.2032	6.7919	9.0997	5:5804	4.6613	4.5644	4.6625	5.0103
83	6.3286	5.3806	6.2132	6.6457	8.7460	6.1096	4.9379	4.8466	5.1143	5.4540
100	5.8247	4.8163	5.7894	5.9553	7.5712	5.1196	4.2773	4.1439	4.2812	4.5171
117	5.1238	4.1468	4.7691	4.6327	6.2970	4.5817	3.7181	3.5245	3.4856	3.6025
132	4.2239	3.5373	3.8256	3.8426	5.2468	3.5266	2.8138	2.5426	2.5596	2.5511

TIME	0Q37	0Q39	0Q40	0Q41	0Q42	0Q43	0Q44	0Q45	0Q46	0Q47
66	5.2114	5.7678	5.8206	6.4225	6.4183	6.4384	7.0004	7.3996	7.5760	8.2175
69	5.2512	5.9187	5.9903	6.6682	6.6905	6.7622	7.3011	7.8068	7.9424	8.6014
83	5.6908	6.2500	6.4720	7.3832	7.4501	7.7398	8.3921	8.8139	9.1433	9.8463
100	4.6311	5.2452	5.5005	6.5786	6.5061	7.1765	7.6554	8.5758	8.8993	9.2919
117	3.5635	4.1037	4.2053	4.7996	4.7899	5.5135	5.7308	6.4313	6.7119	6.7458
132	2.4575	2.9175	2.8819	3.5543	3.4607	4.1898	4.4681	5.2094	5.5634	5.4160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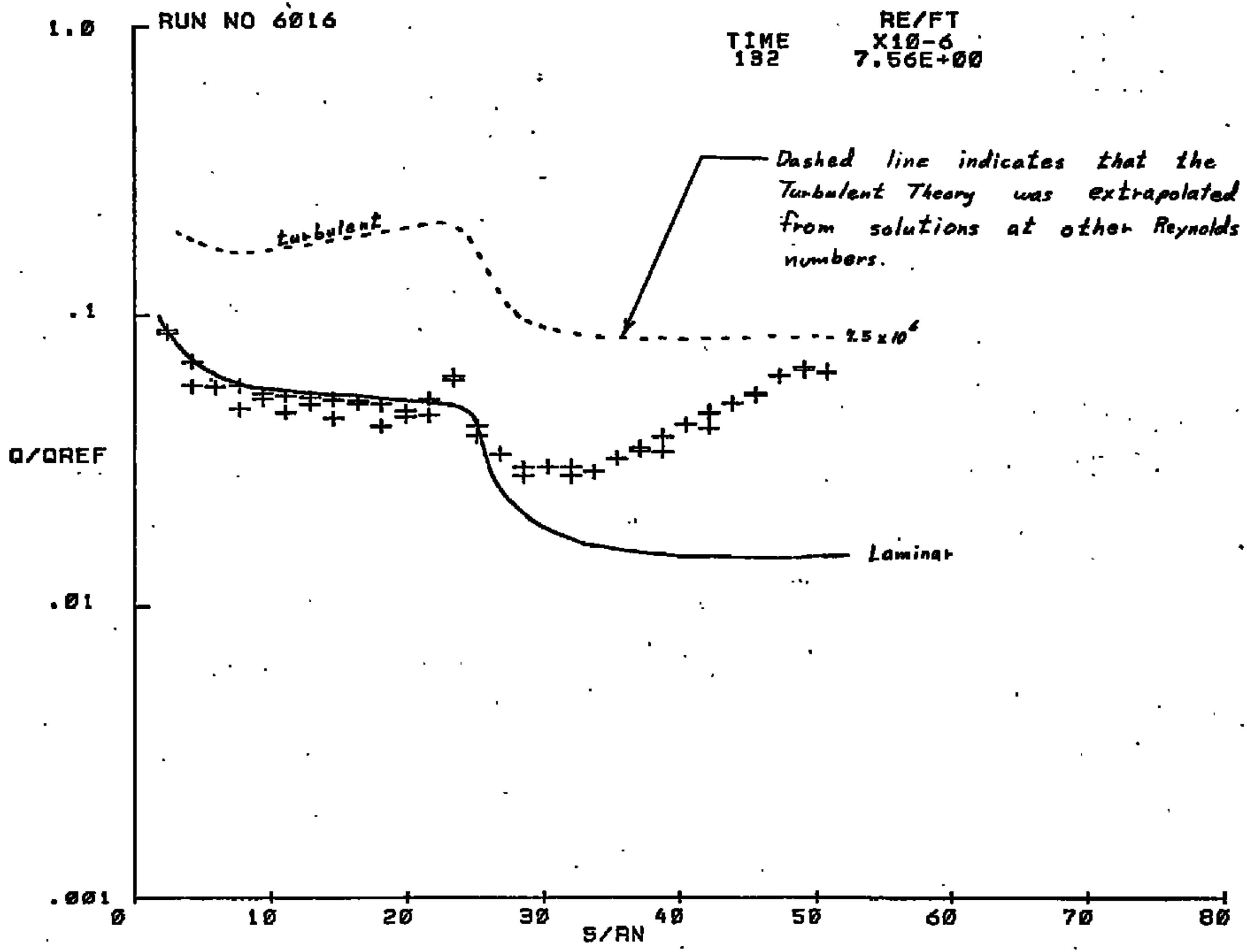
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turbulent
7.5 x 10^6
Laminar
Q/QREF
1.0
.1
.01
.001
0
10
20
30
40
50
60
70
80
S/RN